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Bat diversity in Carajás National Forest (Eastern Amazon) and potential impacts on ecosystem services under climate change

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ABSTRACT

Anthropogenic climate change is one of the main current threats to biodiversity, and it has been linked to species decline. Bats deserve attention because they occupy different trophic niches and perform different functions in nature, acting as flower pollinators (nectarivores), seed dispersers (frugivores), and pest controllers (insectivores). The effects of climate change on the distribution of bat species occurring in the Carajás National Forest (Eastern Amazon, southeastern Pará state, Brazil) was examined by modeling species distributions. A total of 83 species of bats providing the above mentioned services were analyzed for the years 2050 and 2070 to answer the following two questions: (i) Which species are potentially more sensitive to climate changes and will not be able to find suitable areas in Carajás in the future, and (ii) Which are the priority areas that protect the greatest number of species from climate change. Of the total species analyzed, 47 (57%) will potentially not find suitable areas in Carajás under the scenarios employed. Pollinators, seed dispersers, and more-generalist (omnivorous) bats will potentially be the most affected, suffering a 28–36% decrease in suitable area under the 2070 scenario, which may have implications for the plants with which those species interact. According to the scenarios employed, the Carajás National Forest, as well as other conservation units in Pará, will not protect most species in the future. The most suitable areas are located mainly to the north and west of the state and under varying degrees of conservation: from well-preserved protected areas to areas degraded due to different anthropogenic impacts. This study emphasizes that the possible effect of climate change and the location of species protection areas need to be analyzed together to ensure that the areas that will act as potential climate refuges for species in the future are indeed protected.

1. Introduction

Climate change induced by anthropogenic activities has rapidly altered the conditions to which species have adapted locally and, along with deforestation, it is one of the main threats to biodiversity (Titeux et al., 2017). Changes in the area of occurrence of some species were already reported, suggesting some patterns, such as changes in distribution toward the poles (Warren et al., 2001; Tamis et al., 2005) and higher altitudes (Chen et al., 2011). However, more complex, sometimes unexpected, changes have been reported (Gillson et al., 2013); therefore, detailed studies are needed to assess multiple species and regions. Moreover, climate changes affect not only the occurrence of species but also their interactions (Valiente-Banuet et al., 2015). It may alter the structure of interaction networks (Tylianakis et al., 2008), resulting in changes in phenological synchronization (Memmott et al., 2007) or in the geographic distribution of interacting species (Schweiger et al., 2008).

Biodiversity forms the basis of the ecosystem services that support life on the planet (Mace et al., 2012), which have been defined as the benefits that humankind derives, directly or indirectly, from ecosystem functions (Costanza et al., 1997). Ecosystem services have been recognized as resulting from the interactions between several biotic and abiotic components, being necessary to ensure support for society's increasing demands for basic resources such as food, medicines, drinking water, and climate regulation (MEA (Millennium Ecosystem Assessment), 2005). This concept has been widely used to reorganize existing knowledge of biological systems and to guide new research, as it constitutes a key tool to clarify the interface between the use of

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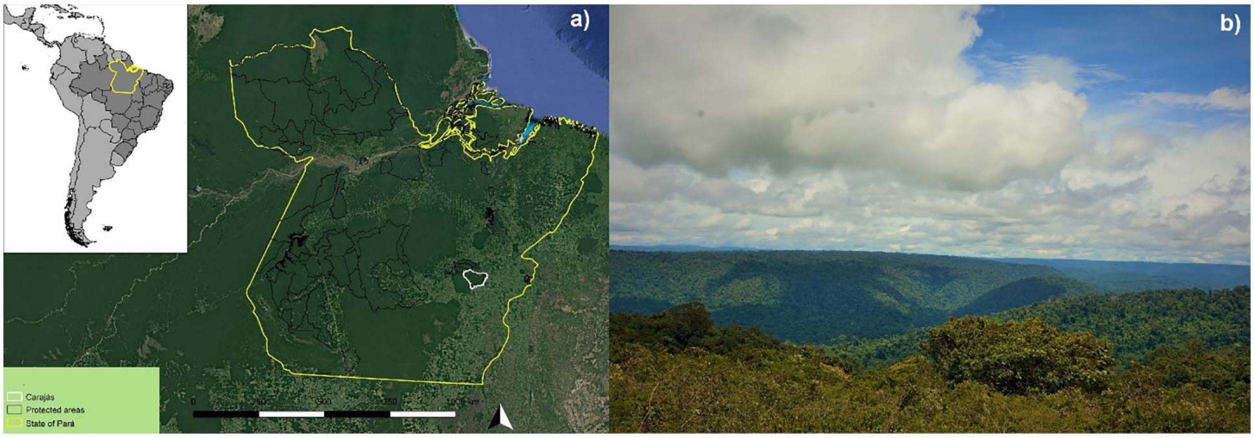

Fig. 1. (a) Carajás National Forest (highlighted in white), located in the southeast of the state of Pará (Brazil), in the Amazon Biome. Black lines on the map indicate conservation units (see also Supplementary Material 3). (b) Photograph of Carajás (author: C.E.P. Silva).

Fig. 2. Examples of bat species occurring in Carajás: (a) *Sturnira lilium* E. Geoffroy, (b) *Anoura geoffroyi* Gray, and (c) *Carollia perspicillata* Linnaeus. Photographs by Robson de Almeida Zampaulo.

natural resources and the need to conserve them (Costanza et al., 2014).

Studies with mobile agents providing ecosystem services (Kremen et al., 2007) (such as bees, birds, and bats that act as pollinators, seed dispersers, and pest controllers) are justified. Those species are particularly sensitivity to spatially operating ecological factors, which makes the services provided by them highly contextual (Kremen, 2005; Mitchell et al., 2015). Pollination and seed dispersal play an important role in determining plant diversity and distribution (Wang and Smith, 2002). Bats have been reported to be associated with hundreds of plant species whose nectar or fruit they consume (Kunz et al., 2011; Ghanem and Voigt, 2012). Frugivorous bats act complementarily with birds that have the same trophic habits, acting together to diversify the microhabitat where those seeds are deposited, thus contributing a significant service when considering the quantity and quality of dispersion (Jacomassa and Pizo, 2010; Sarmento et al., 2014). The initial establishment of plant populations from the action of seed dispersers was also emphasized in cases of forced dispersal due to changes in the climate (Hampe, 2011), land use (McConkey et al., 2012; Ripperger et al., 2015), or restoration of degraded lands (Wunderle Jr., 1997; Hougner et al., 2006; Silveira et al., 2011), Pollinators and seed dispersers are also important for agricultural production, and more than 60 economically relevant species have been listed that may potentially benefit from bats (Kunz et al., 2011). The proximity of forests, as well as caves, was a successful factor in the production of an agricultural crop (*Durio zibethinus* L.) in areas in Thailand, demonstrating the relevance of those habitats as sources of species of nectarivorous and frugivorous bats (Sritongchuay et al., 2016). Insectivorous bats, in turn, include species that are voracious predators of various insects and, hence, act in biological control (Puig-Montserrat et al., 2015). Among bats, species exist with dietary habits that vary from more specialist to more generalist and encompass many insect prey of various sizes and taxonomic groups, such as Lepidoptera, Coleoptera, Diptera, Homoptera, and Hemiptera (Kunz et al., 2011). The importance of bats in the control of pests that lead to losses in the agricultural production of cacao (Maas et al., 2013), coffee (Karp and Daily, 2014), and corn (Maine and Boyles, 2015) has also been demonstrated. In this last example, the value of this service, in terms of the costs saved on pesticides, was estimated at US$ 1 billion per year.

Ongoing changes that affect current and future temperature and rainfall regimes have been identified to be a consequence of the emission of greenhouse gases, and temperature changes may reach, for example, average increases of 2–4 °C by 2050 depending on the scenario analyzed (IPCC, 2014). Local analyses suggest up to a 6 °C increase in temperature by 2070 for the Eastern Amazon region (PBMC, 2013),

Table 1
List of species that will potentially not find suitable habitats in the Carajás region in the future under the climate impact scenarios analyzed.

Family	Genus	Species	Trophic niche
Emballonuridae	*Centronycteris*	*maximiliani*	insectivorous
Emballonuridae	*Diclidurus*	*albus*	insectivorous
Emballonuridae	*Peropteryx*	*kappleri*	insectivorous
Furipteridae	*Furipterus*	*horrens*	insectivorous
Molossidae	*Molossus*	*rufus*	insectivorous
Phyllostomidae	*Ametrida*	*centurio*	frugivorous
Phyllostomidae	*Anoura*	*caudifer*	omnivorous
Phyllostomidae	*Anoura*	*geoffroyi*	omnivorous
Phyllostomidae	*Artibeus*	*lituratus*	omnivorous
Phyllostomidae	*Artibeus*	*obscurus*	frugivorous
Phyllostomidae	*Carollia*	*brevicauda*	omnivorous
Phyllostomidae	*Carollia*	*perspicillata*	omnivorous
Phyllostomidae	*Choeroniscus*	*minor*	nectanivorous
Phyllostomidae	*Chrotopterus*	*auritus*	omnivorous
Phyllostomidae	*Glyphonycteris*	*daviesi*	insectivorous
Phyllostomidae	*Hsunycteris*	*thomasi*	omnivorous
Phyllostomidae	*Lichonycteris*	*degener*	nectanivorous
Phyllostomidae	*Lonchophylla*	*mordax*	omnivorous
Phyllostomidae	*Lonchorhina*	*aurita*	omnivorous
Phyllostomidae	*Lophostoma*	*brasiliense*	omnivorous
Phyllostomidae	*Mesophylla*	*macconnelli*	frugivorous
Phyllostomidae	*Micronycteris*	*microtis*	insectivorous
Phyllostomidae	*Mimon*	*bennettii*	omnivorous
Phyllostomidae	*Phyllostomus*	*hastatus*	omnivorous
Phyllostomidae	*Platyrrhinus*	*brachycephalus*	frugivorous
Phyllostomidae	*Platyrrhinus*	*recifinus*	frugivorous
Phyllostomidae	*Pygoderma*	*bilabiatum*	omnivorous
Phyllostomidae	*Rhinophylla*	*fischerae*	frugivorous
Phyllostomidae	*Rhinophylla*	*pumilio*	frugivorous
Phyllostomidae	*Sturnira*	*lilium*	frugivorous
Phyllostomidae	*Sturnira*	*tildae*	frugivorous
Phyllostomidae	*Tonatia*	*bidens*	omnivorous
Phyllostomidae	*Tonatia*	*saurophila*	insectivorous
Phyllostomidae	*Trachops*	*cirrhosus*	omnivorous
Phyllostomidae	*Trinycteris*	*nicefori*	omnivorous
Phyllostomidae	*Uroderma*	*bilobatum*	omnivorous
Phyllostomidae	*Vampyressa*	*thyone*	frugivorous
Phyllostomidae	*Vampyriscus*	*bidens*	frugivorous
Phyllostomidae	*Vampyriscus*	*brocki*	frugivorous
Phyllostomidae	*Vampyrodes*	*caraccioli*	frugivorous
Thyropteridae	*Thyroptera*	*discifera*	insectivorous
Vespertilionidae	*Eptesicus*	*chiriquinus*	insectivorous
Vespertilionidae	*Eptesicus*	*furinalis*	insectivorous
Vespertilionidae	*Lasiurus*	*blossevillii*	insectivorous
Vespertilionidae	*Lasiurus*	*Ega*	insectivorous
Vespertilionidae	*Myotis*	*nigricans*	insectivorous
Vespertilionidae	*Myotis*	*riparius*	insectivorous

where the Carajás National Forest (southeast Pará state, Brazil), a conservation unit protected by law, is located. Hence, conservation or restoration programs for this area should consider which bat species will be potentially more resistant to such scenarios to ensure success in the medium and long term. Furthermore, assessments of the impact of climate change on service-providing species have become even more critical because of the increasing deforestation of the region. The surroundings of Carajás National Forest have experienced impacts mainly from the expansion of livestock farming and agriculture (Souza-Filho et al., 2016), which potentially intensify the effects of climate change. Indeed, a local increase in temperature of approximately 1 °C and a decrease in rainfall of 0.8 mm/day were cited as possible direct and immediate consequences of deforestation in the Amazon in recent simulations (Pitman and Lorenz, 2016). Thus, Carajás represents an important area of study about the impacts of climate change that can affect the Amazonian biota, since it consists of an area of high biological richness surrounded by areas with high anthropization.

The aim of the present study is to determine the impact of climate change on species of bats occurring in Carajás National Forest, considering their functional role (dietary habit). We employed Species Distribution Modeling (SDM) tools to build models of current and future potential distributions of the bat species. The distribution models assisted in determining (i) which species are potentially more sensitive to climate changes, i.e., those that will potentially not find suitable habitats in the study area in the future, and (ii) which areas are the priority areas for preserving the greatest possible number of species in the future, considering the different services provided.

2. Materials and methods

The study area is Carajás National Forest, a sustainable-use conservation unit located in southeastern Pará (Brazil) (5S 52′ 11″ to 6S 32′ 13″ latitude and 49 W 53′ 28″ to 50 W 44′ 29″ longitude) (Fig. 1). The protection provided by law aims to make nature conservation compatible with sustainable use of part of the natural resources. The Forest, together with other protected areas located around it, form the complex known as the Carajás Conservation Units Mosaic (Mosaico de Unidades de Conservação Carajás) (Gonçalves, 2016). This mosaic of areas consists of one of the few remnants of Amazon forest located in the Eastern Amazon, found in the region of the deforestation arc. It belongs to the Itacaiúnas River Basin, a site under anthropogenic pressure associated with livestock farming and agriculture (Souza-Filho et al., 2016) and with areas used for mineral exploration (Mello and Van-Tilbeurgh, 2009). This mosaic of protected areas currently makes up a fragment

Table 2
Potential impacts of climate changes considering the trophic habit of bat species occurring in Carajás under each scenario analyzed.

Trophic habit	Number of species	Algorithm	Scenario	Number of species that find suitable areas	Remaining species (ID[a])	Impacts on ecosystem services
Frugivorous	16	GLM	2050	2	66, 83	Decrease in seed dispersal
			2070	1	83	
		Maxent	2050	1	22	
			2070	1	79	
Insectivorous	35	GLM	2050	15	1, 10, 19, 37, 43, 47, 48, 49, 51, 53, 54, 63, 64, 72, 77	Decrease in biological control of insect pests
			2070	12	1, 10, 19, 27, 37, 47, 48, 49, 51, 53, 63, 72	
		Maxent	2050	8	1, 2, 10, 47, 49, 51, 64, 72	
			2070	6	2, 10, 19, 47, 51, 63	
Nectarivorous	3	GLM	2050	0	–	Decrease in flower pollination
			2070	0	–	
		Maxent	2050	1	75	
			2070	0	–	
Omnivorous	29	GLM	2050	11	5, 7, 14, 26, 30, 33, 39, 42, 56, 73, 76	Decrease in several aforementioned services
			2070	11	5, 7, 14, 26, 30, 33, 39, 42, 56, 73, 76	
		Maxent	2050	9	15, 25, 33, 50, 57, 65, 74, 76,78	
			2070	4	25, 50, 56, 76	

[a] IDs are available in Supplementary Material 1.

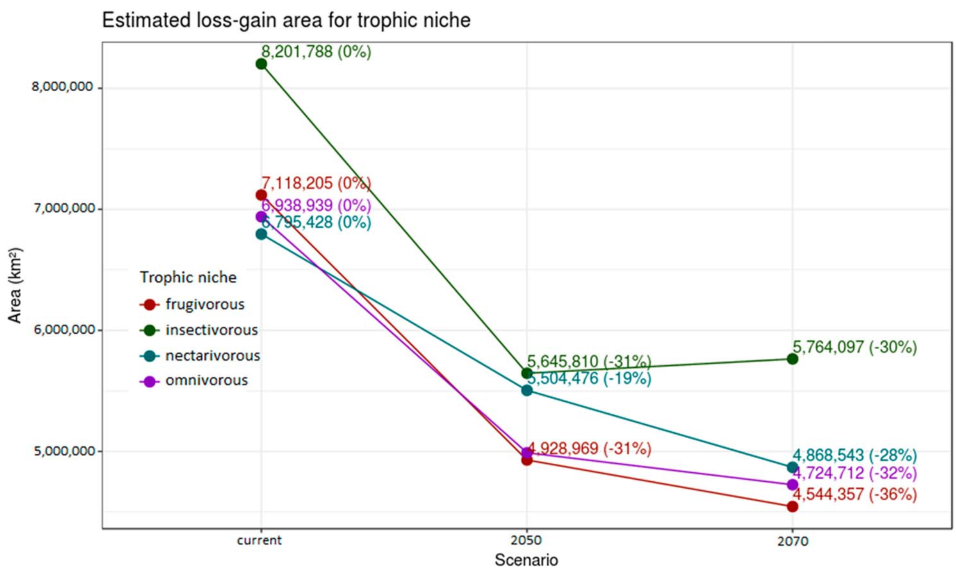

Fig. 3. Potential habitat loss due to climate change for the bat species studied. Percentages refer to mean of all areas for each scenario with values greater than 60% estimated for the maps obtained from the GLM and Maxent algorithms generated for Latin America region.

isolated from other preserved areas (Fig. 1).

The list of bat species reported for Carajás was available in Martins et al. (2012) and was updated based on the work of Nogueira et al. (2014). A total of 83 species were recorded, the majority of which (55 species, or 66%) belong to the family Phyllostomidae (Supplementary Material 1) (Fig. 2). The diet of each species was determined from the literature and consulting specialists. We searched for data about dietary habits presented by Amazonian bats, and found more than 20 references (Supplementary Material 1). The categories nectarivorous, frugivorous, and insectivorous include species cited in the literature as presenting exclusively that type of diet, whereas those cited as having more than one type of diet were classified as omnivorous (Supplementary Material 1). Species with sanguinivorous habits were not included in the present analysis because they are not directly related to ecosystem services, and only three such species have been reported for Carajás (*Desmodus rotundus* E. Geoffroy, 1810; *Diaemus youngi* Jentink, 1893; and *Diphylla ecaudata* Spix, 1823).

Data on the occurrence of each species were organized through 1) research in internal databases on species distribution; 2) research in public online databases containing data on biodiversity, specifically the speciesLink network and the Global Biodiversity Information Facility (GBIF) portals; and 3) a review of specialized bibliography (Supplementary Material 2). Most species show a wide distribution (approximately 0.4–13 million km^2 estimated for South America; Supplementary Material 1); thus, the total known distribution area of each species in South America, subsequently projected for the state of Pará, was used to construct the models. Over 7000 records were obtained for the 83 species.

The biomod2 package (Thuiller, 2003) for R (R Development Core Team, 2005) was used for species distribution modeling (SDM) (Franklin, 2009). Two algorithms were employed: Generalized Linear Model (GLM) (McCullagh and Nelder, 1989) and Maximum Entropy (MAXENT) (Phillips et al., 2006). The environmental variables used for SDM were chosen from among the 20 least-correlated topographic and bioclimatic layers (Aguirre-Gutierrez et al., 2013) of the dataset available in WorldClim (Hijmans et al., 2005) that define altitude and mean temperature and precipitation data for the last 50 years. The following layers were included: Altitude, Mean Diurnal Range, Isothermality, Mean Temperature of Driest Quarter, Annual Precipitation, Precipitation of Driest Month, Precipitation Seasonality, Precipitation of Warmest Quarter, and Precipitation of Coldest Quarter. Model accuracy was assessed with True Skill Statistics (TSS, Allouche et al., 2006) (cut-off threshold = 0.7) calculated from randomizations of 25% of the data.

The future scenarios employed refer to the years 2050 and 2070. A Representative Concentration Pathways (RCP) scenario of 8.5 W/m^2 radiative forcing at the end of the century (IPCC, 2014) was employed, which assumes that greenhouse gases emission will continue to increase in the same manner as in recent years (IPCC, 2014). This scenario was selected because it projects the greatest increase in the emission of such gases and, consequently, the most pronounced changes, since, for conservation purposes, the detection of areas that are most suitable even in more extreme scenarios is important, thereby minimizing costs and maximizing the chance of protecting species. This scenario has been previously employed by other studies (Okazaki et al., 2016; Reside et al., 2017). Projections from the Met Office Hadley Centre (HadGEM2-ES, Hadley Global Environment Model 2–Earth System) and the National Center for Atmospheric Research (CCSM4, The Complete Coupled System Model), available on WorldClim's website, were employed with a resolution of 5 arc min. To generate a single final model that groups the trends defined by both scenarios, the models obtained from the two scenarios (Had and CCSM) were used to construct a combined projection (ensemble forecasting) using pre-existing methodologies (Thuiller et al., 2009). In addition to the aforementioned R package, PostgreSQLs/PostGIS (The PostgreSQL Global Development Group) was used to organize and consult databases. The raster package (Hijmans and Etten, 2012) for R (R Development Core Team, 2005) and QGIS (Open Source Geospatial Foundation Project) were used for map analysis and projection. Notably, only climate data were included in those models because future projections for other variables are not available for Brazil.

The final models were used to analyze patterns of potential future occurrence considering reductions in areas and changes in their location. Species that potentially will not find suitable habitats in Carajás in the future under the climate change scenarios analyzed, i.e., those for which no pixels for occurrence in Carajás were obtained in the future models, were highlighted. To emphasize the impact on the different services provided by the different bat species, the species were analyzed according to their dietary habits, i.e., nectarivorous, frugivorous, insectivorous, and omnivorous. Thus, species models were grouped according to the diets to represent the areas where most species composing each trophic niche may find more suitable habitats. Finally, all species models were grouped to determine priority protected areas that might eventually act as potential climate-refuge areas. Those priority areas were analyzed based on current land cover, using deforestation data for the Amazon rainforest for the year 2015 (PRODES; http://www.obt.inpe.br). The degree of protection of those areas was also considered, and data on Brazilian conservation units available on the

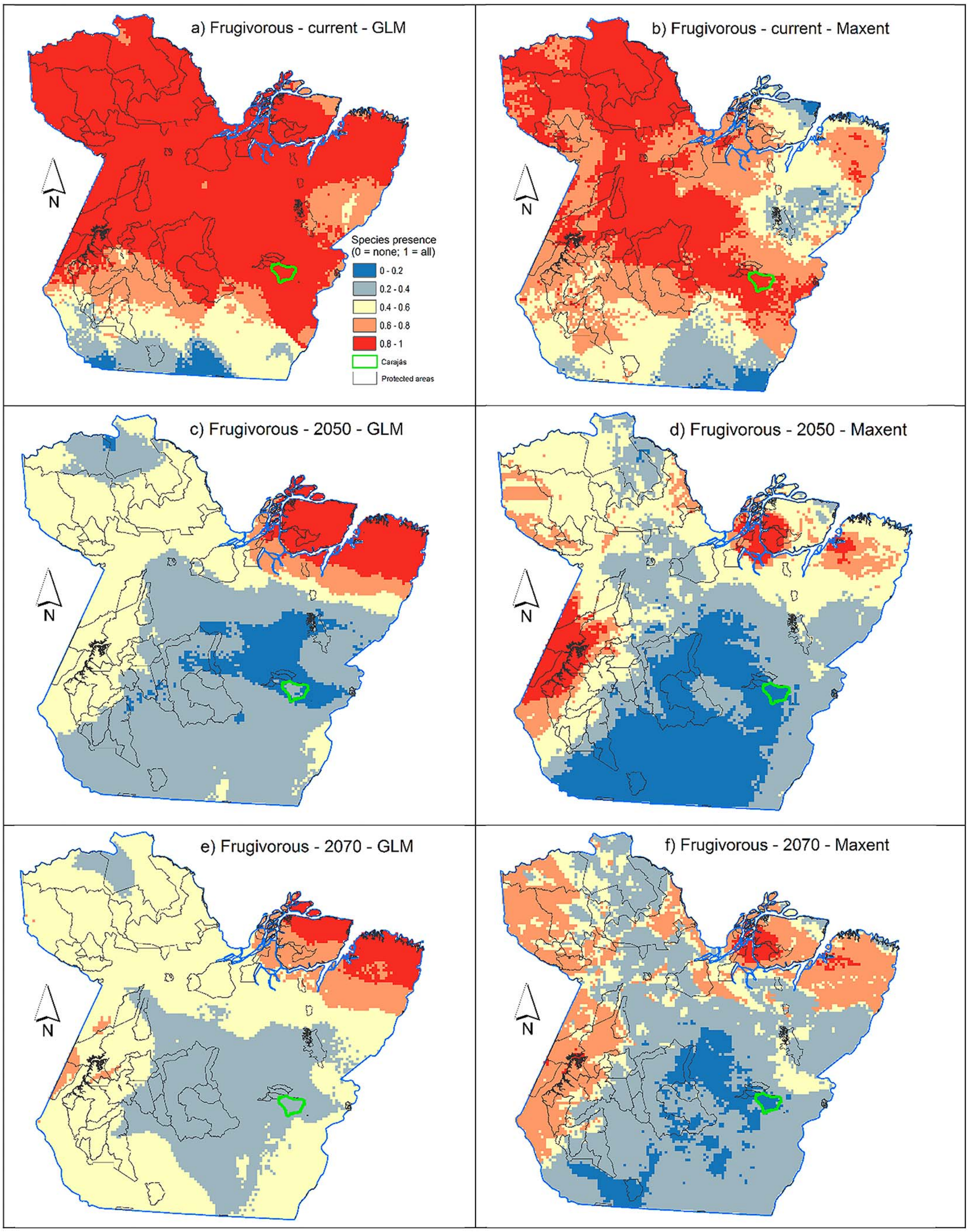

Fig. 4. Potential effect of climate change on frugivorous bat species considering three scenarios (current, 2050, and 2070) and two models (GLM and Maxent) occurring in Carajás.

website of the Chico Mendes Institute for Biodiversity Conservation (Institute Chico Mendes de Conservação da Biodiversidade – ICMBio; http://www.icmbio.gov.br) were used for this assessment.

3. Results

Approximately 47% of the species analyzed (36 species out of a total of 83) will potentially find suitable habitats in Carajás in the future under any of the climate change scenarios analyzed. The remaining species (57%, 47 species) will potentially not find suitable habitats in Carajás under those scenarios (Table 1).

Depending on the scenario, of the 16 species identified as exclusively frugivorous, possibly only two will find suitable climatic conditions in the future (Table 2). Of the 35 species identified as insectivorous, 6–15 will potentially find suitable habitats. The nectarivorous species of Carajás (total of three) will potentially be the most threatened, with possibly a single species finding suitable habitats in the region by 2050. For omnivorous, of the 29 species identified, 4–11 species will find suitable habitats. In terms of loss of area, frugivorous, insectivorous, and omnivorous species will have a potential reduction in suitable areas of approximately 30% for 2050, whereas nectarivorous species will have a potential reduction of 20% (Fig. 3). For 2070, these species show a potential area reduction of 28–36%.

Both models (GLM and Maxent) suggest future areas of potential occurrence in the north and southwest of Carajás as being the most suitable for frugivorous species, with a decrease in suitability for the 2070 scenarios (Fig. 4). Few species (less than 20%) will potentially find future suitable habitats in Carajás. The suitable areas obtained for

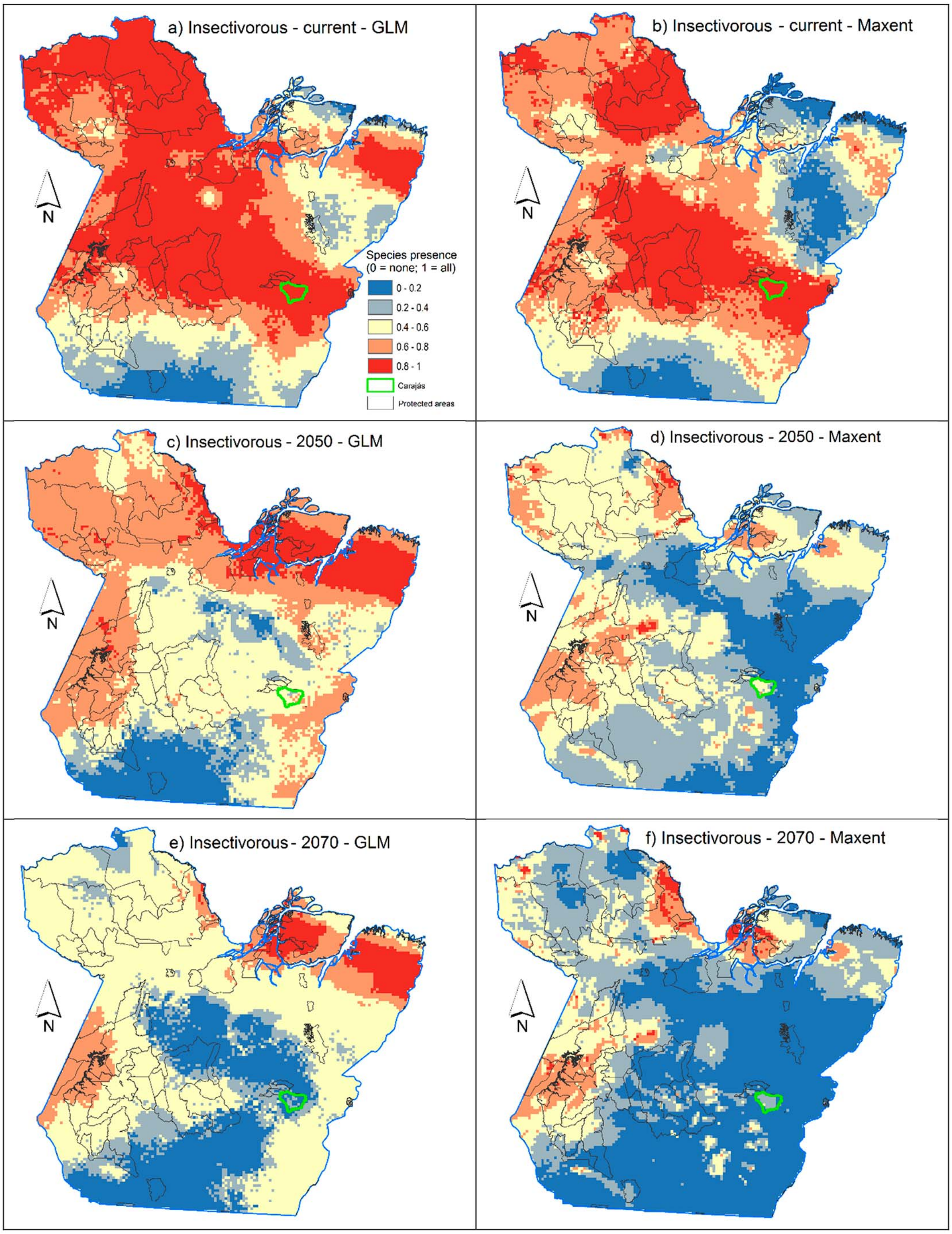

Fig. 5. Potential effect of climate change on insectivorous bat species considering three scenarios (current, 2050, and 2070) and two models (GLM and Maxent) occurring in Carajás.

some insectivorous species (40–80%) were presented on future models, especially on those obtained from Maxent (Fig. 5). Areas to the north and southwest of the state were also indicated as the most important for future scenarios, potentially protecting a greater number of species (more than 80%), with a decrease in suitability by 2070 (Fig. 5). The models highlight areas to the north and southwest also for nectarivorous species for 2050, with a marked decrease in suitability for 2070 (Fig. 6). According to the projections, some areas remain suitable inside and outside Carajás for some omnivorous species in the future, but these areas also show a potential decrease for 2070 (Fig. 7). The areas to the north and west were identified as potentially relevant areas for most species.

Priority areas for the protection of bat species in the state of Pará, defined as the sites where most species will find potential suitable habitats in the future, are located especially in the northern and western parts of the state (Fig. 8). Those areas are the most interesting for consideration as potential climatic refuges for species protection, and some of them are already conservation units (Supplementary Material 3), whereas others are areas currently degraded by anthropogenic action. Under the current scenario, 99.7% of the priority areas potentially suitable for more than 40% of the species are inside conservation units on Pará State (Table 3). For 2050, this percentage corresponds to 41.1%. Finally, for 2070, the percentage of priority areas inside conservation units declines to 14.1%.

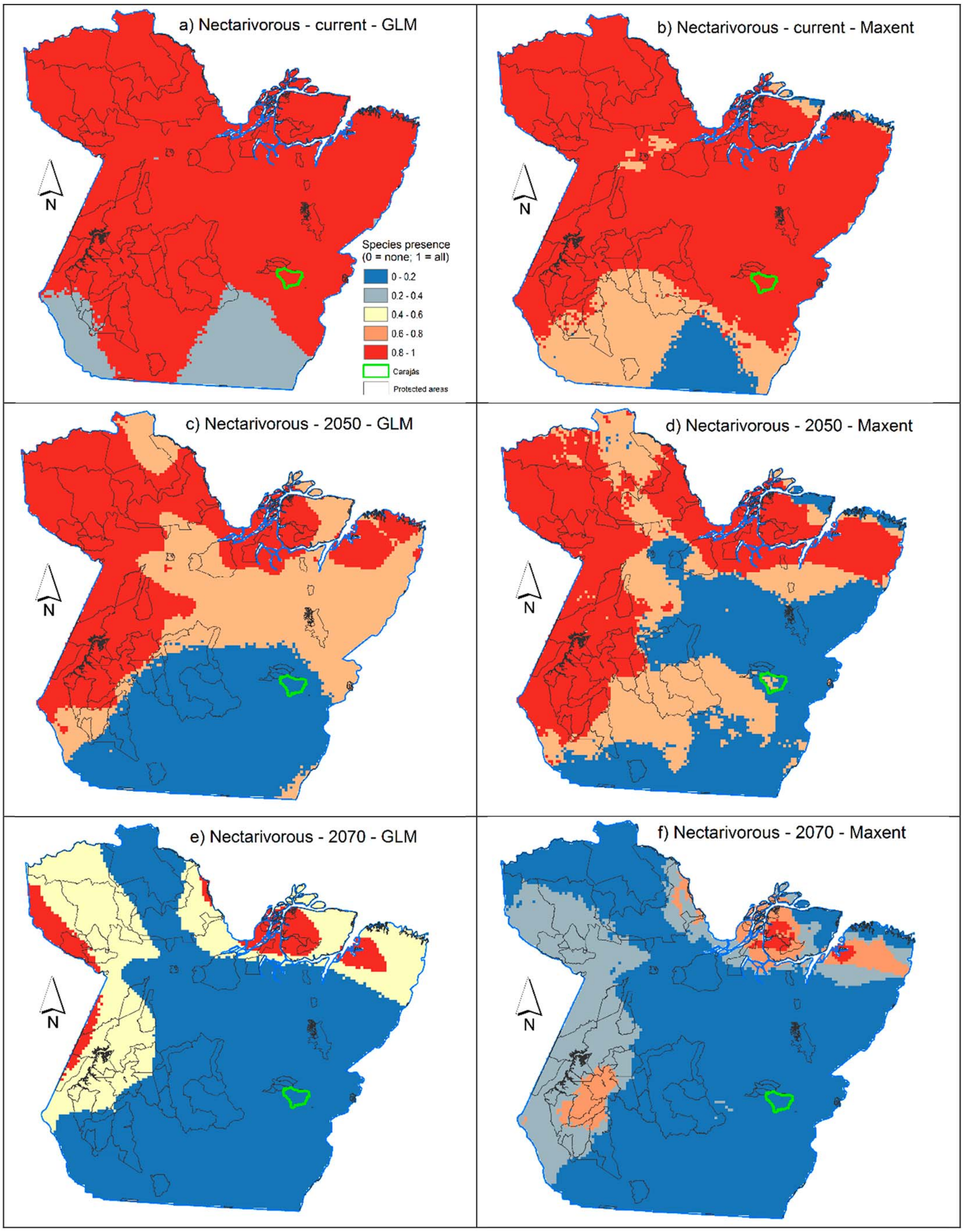

Fig. 6. Potential effect of climate change on nectarivorous bat species considering three scenarios (current, 2050, 2070) and two models (GLM and Maxent) occurring in Carajás.

4. Discussion

More than half of the species occurring in Carajás will potentially not find suitable habitats in the future scenarios analyzed. Emphasis should be placed particularly on the three species with exclusively nectarivorous habits that occur in the region, among which, only a single species will potentially find suitable habitats in the future. However, other areas outside of Carajás might present suitable habitats, and some are already protected by conservation units, which could assist in the preservation of the areas. It is important to consider that we used the climate scenario projecting the most intense climate change, and the results might be less pronounced if those projections are not confirmed. However, the projections of these more extreme scenarios do not seem far from reality (Rahmstorf et al., 2007; Peters et al., 2013), and considerable efforts will be needed to mitigate the effects of those changes for the future. Moreover, the results obtained from those scenarios emphasize areas that, even under extreme conditions, will present suitable conditions for those species, which is useful when considering conservation.

The decrease in suitability for the bat species analyzed in Carajás is particularly worrisome regarding the decrease in the supply of ecosystem services. The impact on bat species may have implications for the plants with which those species interact. The relevance of those species to natural areas has been emphasized previously, with approximately 250 plant genera being cited as pollinated by bats (Sekercioglu, 2006), making up more than 500 species (Kunz et al., 2011). In addition to the natural areas in Carajás, the surrounding region produces agricultural crops that might also benefit from the

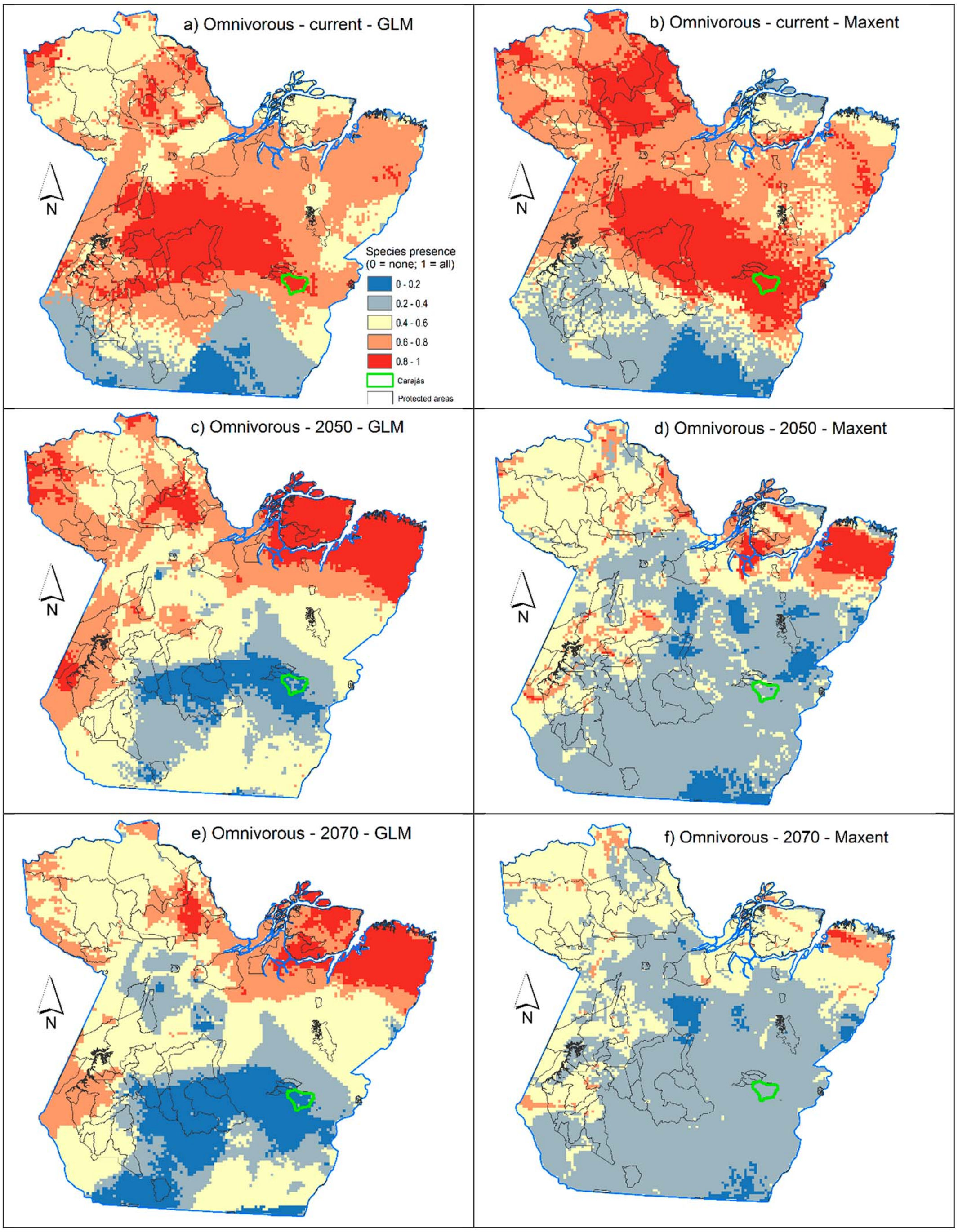

Fig. 7. Potential effect of climate change on omnivorous bat species considering three scenarios (current, 2050, and 2070) and two models (GLM and Maxent) occurring in Carajás.

ecosystem services provided by bats. The municipalities around Carajás produce açaí, coffee, papaya, passion fruit, heart of palm, and pepper, according to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia & Estatística – IBGE), and might benefit directly from seed dispersal by bats (Kunz et al., 2011). Considering the state of Pará, in addition to the six crops mentioned, cashew and guava (seed dispersal) and mango (pollination) production stand out (Kunz et al., 2011). However, this still needs to be addressed adequately with field work aiming to rigorously define interactions between bats and flora in the region. Potentially, other species of pollinators and seed dispersers should interact with such plants, participating on their reproductive processes. Thus, bat interactions with flora species inside and outside Carajás need better evaluation, so the impact of the loss of bat species in the region can be estimated with accuracy.

Two situations stand out regarding priority areas that could potentially act as climatic refuges. First, those areas differ in their degree of preservation. The areas to the west, particularly on the border with the state of Amazonas, and one of the areas to the north, equivalent to the Marajó Archipelago, are still well-preserved. In contrast, the area to the north and east of Marajó is currently more degraded due to anthropogenic action, and few species are likely to find nesting and foraging areas to ensure their survival in that region. Second, some of these areas are currently protected by conservation units, as is the case of the Environmental Protection Area of the Marajó Archipelago (Área de Proteção Ambiental do Arquipélago de Marajó) to the north and other Units to the west of Pará (Supplementary Material 3). Conversely, some new areas would need to be researched as, according to the models, they could be considered areas for species protection. The

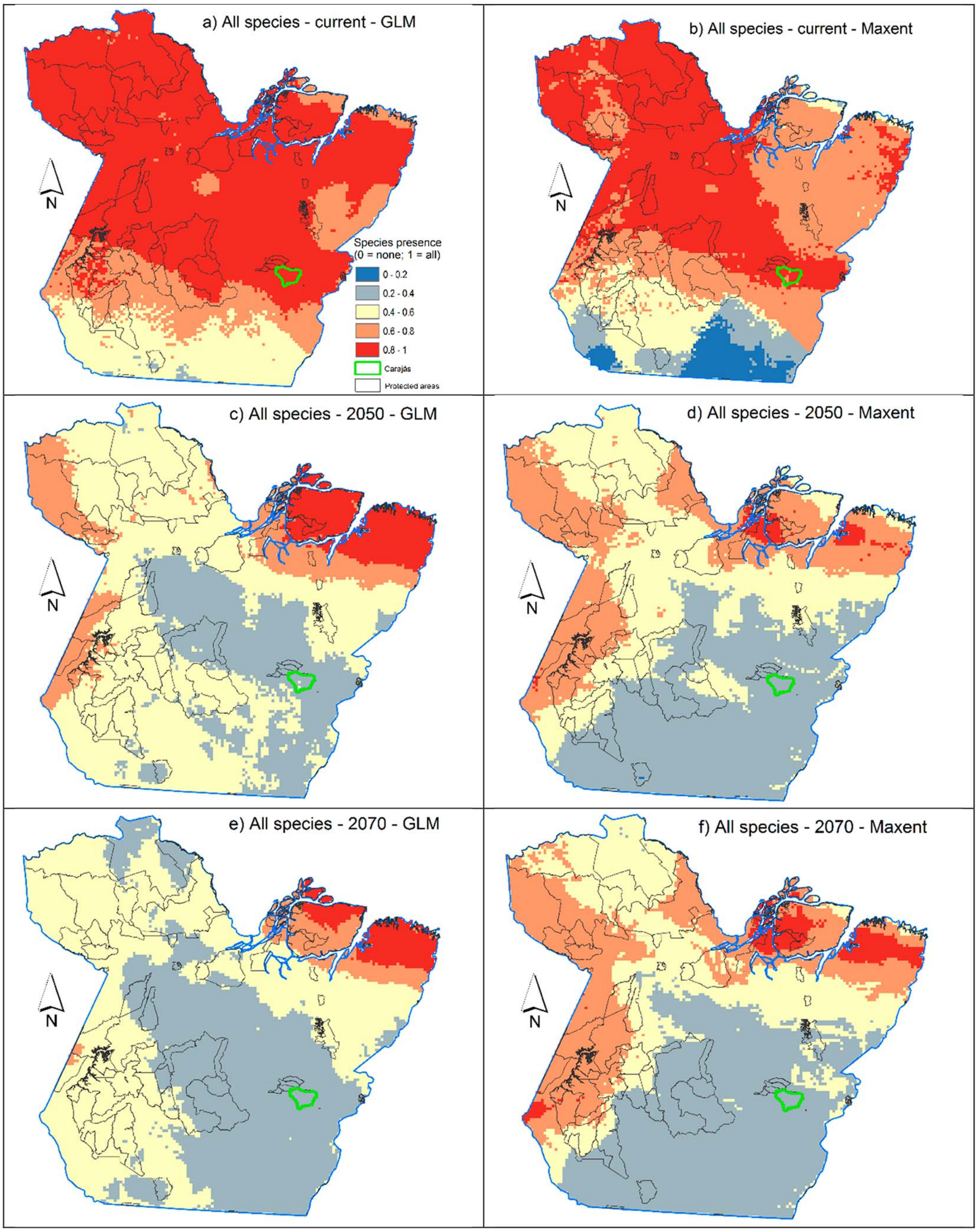

Fig. 8. Potential effect of climate change on all bat species considering three scenarios (current, 2050, and 2070) and two models (GLM and Maxent) occurring in Carajás.

Table 3
Total priority areas for bats occurring in Carajás, considering climate changes, that are protected by conservation units. Total extension of conservation unit areas on Pará state is currently 404.933km^2. Priority areas were defined as those whose pixels show more than 40% of species present for the current scenario. A total of 83 species were analyzed.

Scenario	Total priority area within CU (km^2)	Percentage considering the total extension of conservation units (%)
Current	403,854	99.7
2050	166,413	41.1
2070	56,927	14.1

impact of climate change on species biodiversity and the degree of protection represented by conservation units in Brazil have been previously examined. Scenarios for bird species (Marini et al., 2009; Machado and Loyola, 2013) and nonflying mammals (Faleiro et al., 2013) demonstrated that, in some cases, those units potentially will be ineffective in protecting biodiversity. Carajás, as the models indicate, will not have climatically suitable areas to protect some of the species analyzed. The impact of climate change and the status of species protection areas need to be analyzed together to ensure that priority areas are indeed protected, thus creating possible corridors allowing the migration of endangered species.

A necessary future step consists of further studies on interactions between the bat species and flora of Carajás. This step is fundamental for examining the results of the impact on flora species with which bat species, especially those that are nectarivorous, interact. A better understanding of the role of species with generalist trophic habits, which are potential service providers in degraded areas, and those with specialist habits, as their interactions are narrower, which could have more

severe implications for their protection, is essential. In addition, the ability of bats to move to other areas (Voigt et al., 2017) needs also to be better evaluated, since this ability will be critical on the capacity of species to find new suitable areas and survive to climate changes (Sherwin et al., 2013). Finally, most climate-change-impact projections still fail to assess whether species will be able to adapt to those changes in a timely manner (O'Neill et al., 2017), making such studies of paramount importance.

5. Conclusions

The bat species occurring in Carajás will potentially be affected by climate changes. Consequences relative to interactions with flora may involve an absence of pollination and dispersion vectors, as well as decreased biological control of insect pests. The results also showcase that, according to the models, Carajás will not efficiently protect some of the bat species analyzed, and most priority areas are located to the north and west of the state of Pará. Some sites where species will find future suitable habitats are in good preservation conditions, and some are within conservation units. However, although other important areas are in considerably well-preserved regions, they are not protected; therefore, additional studies on the possibility of protecting those areas are suggested. Moreover, important areas were identified in sites that are currently considerably degraded and not likely to serve as protection areas for species in the future. The need for further studies on the biology of the species and their patterns of occurrence and interactions is emphasized, so that conservation strategies are more efficient.

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